

Naval Surface Warfare Center Carderock Division

West Bethesda, MD 20817-5700

NSWCCD-63-TR-2006/36 January 2007

Survivability, Structures, and Materials Department
Technical Report

Correcting the Response of an Albedo Neutron Dosimeter for Energy

by

Gordon K. Riel and Patrick J. Winters
Naval Surface Warfare Center

James R. Cassata, LCDR, MSC, USN
Bureau of Medicine and Surgery, Washington DC

Ted St. John, LCDR, MSC, USN
Naval Medical Center Portsmouth, Portsmouth, VA

Luis A. Benevides, CDR, MSC, USN
Naval Dosimetry Center, Bethesda, MD



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NAVAL SURFACE WARFARE CENTER
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1. Reference (a) provided funding and direction for work related to the quality assurance for neutron dosimetry with the DT-702 PD. Enclosure (1) provides baseline data and procedures for correcting response according to neutron energy using either the AN/PDR-70-RADIAC or the SS-20 neutron area monitor.

2. NSWCCD continues to remain abreast of this evolving technology and stands ready to assist in meeting future requirements. Comments or questions may be referred to Dr. Gordon K. Riel Code 6301; telephone (301) 227-5666; e-mail, Gordon.Riel@navy.mil.

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Enclosure (1)

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Administrative Information

The New Ship ESOH and Emerging EQ Technologies Program Office (Code 6301), Environmental Quality Division (Code 63) of the Survivability, Structures and Materials Department at the Naval Surface Warfare Center, Carderock Division (NSWCCD), performed the work described in this report. The work was funded by the Naval Sea Systems Command, Work Request N0002404WX30176.

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Acronyms

BF3	Boron triflouride gas (filling the neutron detecting proportional counter tube)
NATO	North Atlantic Treaty Organization
NDC	Naval Dosimetry Center
NECF	neutron energy correction factor
NIST	National Institute of Standards and Technology
NNPP	Naval Nuclear Propulsion Program
NRL	Naval Research Laboratory
NSWCCD	Naval Surface Warfare Center, Carderock Division
RADIAC	radioactivity, detection, indication and computation
SSBN	ballistic missile submarine
TLD	thermoluminescent dosimeter
USNA	United States Naval Academy

Introduction

The neutron response of an albedo neutron dosimeter varies greatly with energy (Glickstein, 1981). For a correct result, the measured dose equivalent reported is multiplied by a neutron energy correction factor (NECF). The dosimeter, calibrated with moderated Californium fission neutrons, will read more than 30 times the dose from thermal neutrons and less than 3% of the dose from 14 MeV neutrons. NECFs can be calculated by using the count rate ratio of the AN/PDR-70 neutron remmeter to its internal parts or from the ratio of the inner to the outer neutron dosimeters in the DETECTOR RADIAC SS-20/S (NAM-5).

Why not determine NECFs by measuring the dose rate and the response of dosimeters on phantoms? This was attempted first, but it resulted in low dose rates and the thermoluminescent dosimeters (TLDs) had to be left on the phantoms for six weeks. Six of seven sets of TLDs came back with unreasonable doses, so this methodology was rejected and the procedure described in this document was devised. At first, NECFs were calculated by measuring neutron spectra and weighting them with the albedo TLD neutron energy response. Then a ratio procedure was used [Hankins, 1976] and an energy independent area monitor was developed which was the predecessor of the NAM-5 described here. Most of the early work was done with shielded and moderated Cf^{252} and PuBe sources at NRL and monoenergetic neutron beams at the NIST reactor. Later tests used neutron beams from the NSWCCD positive ion accelerator facility, Cf^{252} sources at NIST, and 14 MeV and PuBe neutrons at the USNA.

Thermoluminescent Dosimeters (TLD)

The Navy has formally monitored personnel for occupational exposure to ionizing radiation since at least 1946. Navy radiation dosimetry development is a dynamic process. The first Navy TLD for radiation measurement, the DT-526/PD, was introduced in 1973 for monitoring personnel exposed to gamma radiation associated with naval nuclear propulsion plants (NNPP). The first TLDs used by the Naval Dosimetry Center (NDC), the DT-583/PD followed by the DT-648/PD in 1988 for non-NNPP personnel, were very similar to the ones used today, but the technology has improved significantly [Moscovitch, 1999; Cassata, 2002; Devine, 1990].

The current system used by the NDC, the DT-702/PD, shown in Figure 1, is the Harshaw 8840 holder and 8841 card. The primary reasons for switching to the DT-702/PD were to meet the increasingly stringent requirements set by the National Voluntary Laboratory Accreditation Program (NVLAP) using HPS/ANSI N13.11-2001 testing standards and to provide a replacement dosimeter for the DT-526/PD technology. A detailed description of the DT-702 and issues with its neutron response are found in Cassata [2002]. Quality assurance and the large-scale use of the DT-702 are discussed in T.J. St. John [2006] and M. Moscovitch [2006].

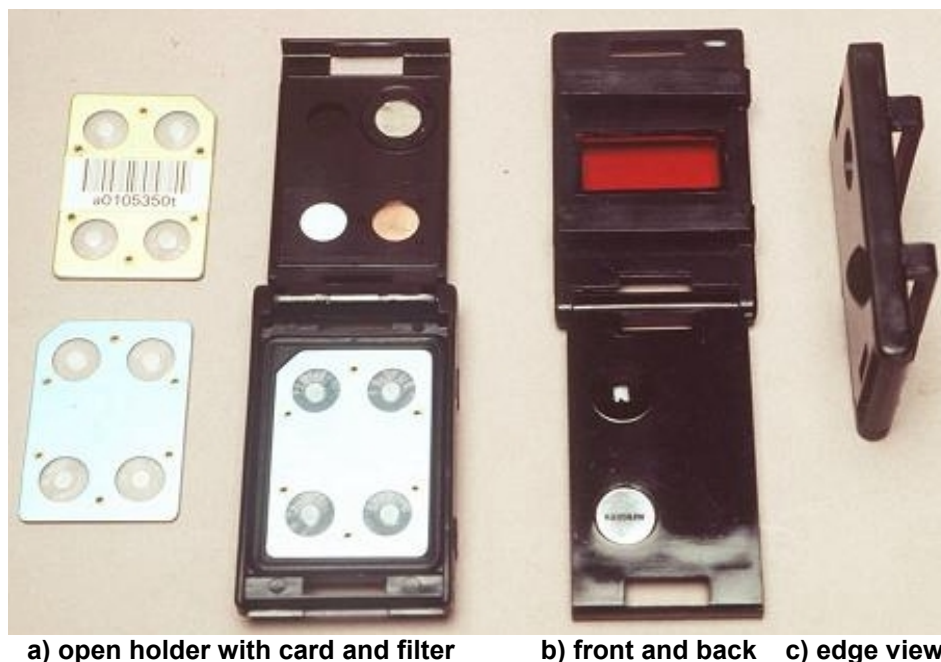


Figure 1. DT-702/PD Cards

Should an albedo dosimeter have a filter to reduce its response to incident thermal neutrons? Not if the loss in efficiency is greater than the gain in uniform energy response. One improves the energy response of albedo dosimeters only by reducing their response to the low energy portion of the spectrum, resulting in a loss of sensitivity. It will now be shown that the energy error can be corrected. Low sensitivity leads to zero doses in many reports, and zeros cannot be corrected. Do correction factors matter at low doses? Yes, because a dosimeter with a neutron reporting threshold dose of 2 mrem in a field where the response per rem is 0.04 will fail to report 50 mrem. The DT-583, which has a cadmium filter, was compared with the DT-648, which has no thermal neutron absorber. The DT-648's variation with energy from bare AmBe to Cf^{252} in a 60 cm iron ball is 21.5, while the DT-583's variation is 16.8. So the DT-648's variation with energy is only 30% larger than the DT-583, and the DT-648 is 2.3 times as sensitive (in neutron to Cs^{137} equivalent). So, eliminating the thermal neutron filter made a poor energy response slightly worse, but it produced a worthwhile gain in sensitivity.

Detectors for Energy Correction

NECFs are calculated from count rate ratios of the AN/PDR-70 neutron remmeter to its internal parts or from the ratio of the outer to the inner neutron dosimeters in the DETECTOR RADIAC SS-20/S (NAM-5).

AN/PDR-70 rem/Guts

This neutron remmeter moderator/shield is made from two concentric cylinders of polyethylene with a perforated borated rubber shield between them, Figure 2. The remmeter response is called "rem". The "Guts" is the inner, 3-inch diameter, cylinder with the BF3

proportional counter tube in the center. A regression of response versus energy of the Guts and a neutron albedo TLD on a phantom show that the Guts is a close analog of the albedo response. So the rem/Guts ratio may be used to correct the energy response of the dosimeter. This method, described in Appendix A, Procedures for Determining Neutron Energy Correction Factors Using the AN-PDR/70 RADIAC, may be applied in fields as low as 10 mrem per six-week issue period by counting for 80 minutes with the Guts and AN/PDR-70.



a) Exploded View



b) "Guts"

Figure 2. AN/PDR-70

NAM-5 In/Out

The NAM-5, Figure 3, has a moderator/shield, similar to the AN/PDR-70 remmeter, except it is designed to accept a pair of thermoluminescent dosimeter (TLD) cards instead of the thermal neutron counting tube. Four pairs of cards around the circumference measure the albedo response. So the ratio of the inner to outer cards, "In/Out" may be used to correct the energy response of the dosimeter. Useful results are obtained when the dose is at least 50 mrem per issue period.



The drawers are partly removed, and one of four circumferential drawers is on the table. Each drawer can hold two cards.

Figure 3. Detector RADIAC SS-20/S (NAM-5)

Result

The relative response of the Guts to the albedo neutron response of LiF is nearly constant over most of the spectrum; see Figure 4. The response of the neutron albedo TLD varies by a factor of 1,400 over the energy range from thermal to 14 MeV. NECFs correct the response so that the factor of 1,400 is reduced to 2.4 by the remmeter method and to 5.2 by the NAM-5 method.

$$NECF = 9.1(\text{rem/Guts}) = 9.1(\text{In/Out})$$

The corresponding bias + standard deviation results are 37% and 51%. Part of this variation is due to the error in measuring the response of the six items: the actual dose equivalent, the albedo TLD response, and the response of the two ratio devices. Only five fields were available for the DT-702 TLD. Fifteen fields (many well verified by replications and including the NATO standard battlefield environment and an SSBN) were used to fit the DT-648 TLD NECF with a bias + standard deviation of 24%. Since there was no significant difference between the coefficients of the DT-648 Guts/rem, the DT-702 Guts/rem and the NAM-5 Out/In, the same constant was selected for all.

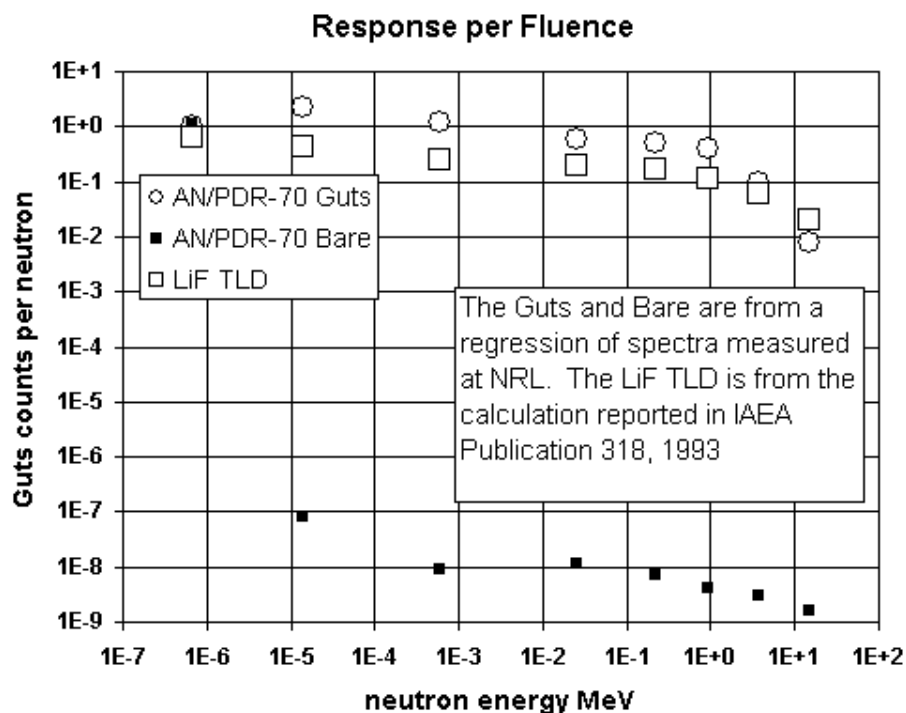


Figure 4. Relative Response of the Guts to the Albedo Neutron Response of LiF

The Guts and the NAM-5 outer cards measure the albedo response and the AN/PDR-70 and the NAM-5 inner cards measure the dose equivalent, so the ratios (Guts/AN/PDR-70) and (Out/In) measure (TLD/rem), which is the inverse of the NECF. One would also hope that the ratio would be independent of the measurement method, and it is, to a degree, as seen in Figure 5. At higher energies, where the ratios are small, the Guts/rem shows more change with energy than the NAM-5 Out/In.

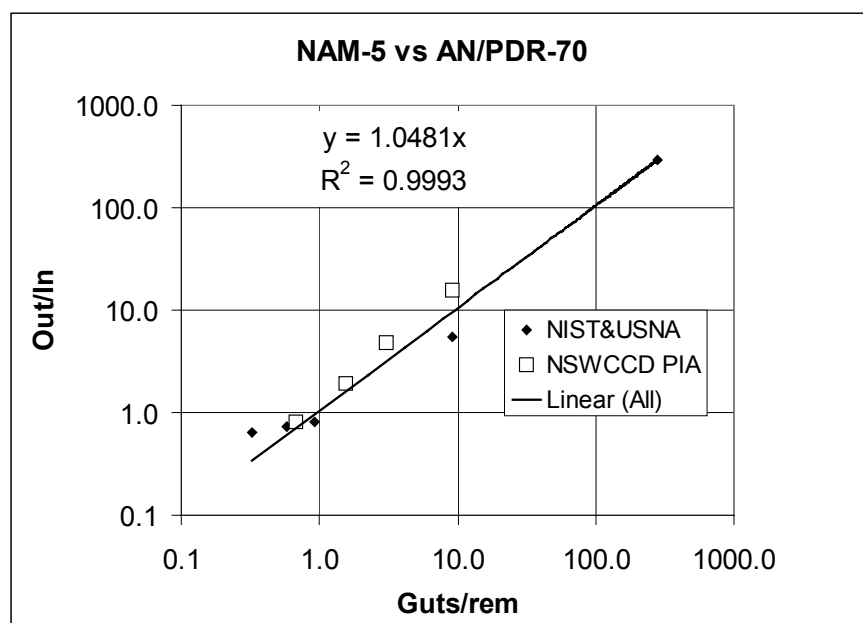


Figure 5. NAM-5 vs. AN/PDR-70

Determining the NECF by Finding the Coefficient

NECF=K1(In/Out)=K2(rem/Guts). What is the best value of the constants where K1 is the NAM-5 constant and K2 is the AN/PDR-70 constant? How do the two methods compare? K1 and K2 are about equal as might be expected since the AN/PDR-70 and the inside cards of the NAM-5 both measure the dose equivalent while the Guts and the outer cards in the NAM-5 track the albedo response. The best fit to the measured response is:

$$\text{NECF}=9.0 (\text{In/Out})=9.2(\text{rem/Guts}), \text{ and DT-648 NECF}=9.1(\text{rem/Guts})$$

There is no real difference, therefore: $\text{NECF}=9.1(\text{In/Out})=9.1(\text{rem/Guts})$.

Table 1. Finding K (NECF) that Best Fits the Measured TLD Response

		All Data K1=K2=9.1			Best fit to Individual Data		
		BOTH	NAM-5	AN/PDR-70	BOTH	NAM-5	AN/PDR-70
	K	9.100	9.100	9.100	9.114	9.031	9.198
	Bias	-0.2%	0.8%	-1.1%	0.0%	0.0%	0.0%
	S	41.4%	50.4%	36.2%	41.5%	50.1%	36.6%
	B+S	41.6%	51.2%	37.3%	41.5%	50.1%	36.6%
		1998	2003	1994	NECF=K1(In/Out)=K2(rem/Guts)		
	Measured	Measured	Measured	Calculated	Calculated	Calculated	Calculated
	NECF	NAM-5	AN/PDR-70	NECF	NECF	Pi	Pi
Neutron Source	DT-702	Out/In	Guts/rem	NAM-5	AN/PDR-70	NAM-5	AN/PDR-70
USNA PuBe (4.0-4.5 MeV)	14.38	0.81	0.92	11.30	9.88	-21%	-31%
NIST Moderated Cf (0.5 MeV)	1.00	5.41	9.09	1.68	1.00	68%	0%
NIST Bare Cf (2.0-2.3 MeV)	10.14	0.73	0.58	12.48	15.69	23%	55%
USNA Fast 14.2 MeV	43.43	0.64	0.32	14.15	28.15	-67%	-35%
NIST Thermal (0.0375 eV)	0.030	294.59	281.14	0.031	0.032	1%	6%

Establishing an Energy Correction Procedure

$$\text{DT-702 RESPONSE/REM} = f(\text{AN/PDR-70, GUTS, BARE})$$

where $f()$ is a function to be determined.

1. Measure field spectra.
2. Build similar spectra in the laboratory.
3. Measure TLD, NAM-5 In and Out, AN/PDR-70 rem and Guts and dose equivalent response in these spectra.
4. Find the model that best predicts the measured TLD response.

The steps of modeling:

1. Get a good set of data.
2. Model the physics and/or find the minimum number of non-zero coefficients.
3. Find the value of the coefficients.

Good Data

The data should represent the range without over representing any part of it. Initially, nearly 100 spectra in fields that had been built at NRL were selected to challenge the energy response of neutron measuring devices. None of those available in 1978 matched measured

shipboard spectra, so new fields were made using 25 and 60 cm of iron for the moderator/shield [Nash, et al, 1985]. Many of the 100 spectra were very similar. Fitting all would have favored them over the unique spectra. Spectra were selected that were nearly equally spaced over the response/rem range. Spectra were further selected to represent those measured in the field and to contain the maximum, minimum, and mean values of the response ratios Guts/AN/PDR-70 and Bare/AN/PDR-70. Nine spectra filled all of these requirements. Systems were tested in these spectra in 1985, 1994-5, and 1998-9. The 1985 data set had two wrong results, while in 1999 the Cf source activity was too low. The best values for the ratios and the dosimeter response were used, even if these were measured in different years. This set was augmented with the National Institute of Science and Technology (NIST) thermal and bare and moderated Cf²⁵², the US Naval Academy's (USNA) 14 MeV (and in 1998 PuBe), NATO Battlefield [Johnson, Drischler, and Barnes, 1991], and Submarine data. Measuring at three distances and using the regression of Eisenhower [1987 and 1992] to remove the response to scattered neutrons, resulted in the response to a pure 14 MeV field. (The DT-648 is calibrated to NIST moderated Californium, but its response is 1.021 instead of 1.00.) Table 2 shows the larger set that was used to determine the DT-648 NECF.

Table 2. DT-648 Data

FIELD	DT-648 to rem	Guts to AN/PDR-70	Bare to AN/PDR-70	rem per AN/PDR-70
14 MeV	0.039	0.323	0.014	1.914
NRL # 2	0.089	0.773	0.019	1.204
Bare Cf	0.100	0.580	0.016	1.000
NRL # 1	0.108	0.921	0.190	1.228
NRL # 13	0.154	1.272	0.239	1.030
NRL # 38	0.370	3.809	0.066	0.904
NRL # 11	0.417	3.153	1.404	1.198
NRL # 29	0.459	4.275	0.819	0.992
Submarine	0.519	5.980	0.629	1.191
NATO	0.701	8.985	3.823	0.899
NRL # 46	0.946	11.782	0.545	0.912
D20 Cf	1.021	9.090	0.788	0.840
NRL # 47	2.773	19.860	10.712	0.984
NRL # 45	2.801	18.653	8.992	0.943
Thermal	28.253	240.873	378.200	3.894

The Algorithm, How Many Parameters?

Letting the data determine the algorithm can lead to trouble, now that hundreds of functions are available in easy to use programs. Jeffreys [1992] shows that a sixth order polynomial fits Galileo's data on the acceleration of gravity better than a quadratic. Galileo may never have been heard of, if he had a computer. The point is that, if one does not know the physics, one should use simple functions with few adjustable parameters. The physics are known, but a minimum number of parameters is still sought.

The Algorithm, Modeling the Physics

The response of a device in a field may be determined by the weighted sum of the responses of other devices. This works well when the responses of the other devices are orthogonal, as in the Bonner multi-sphere spectrometer.

$$R = \sum k_i r_i \text{ where}$$

R = the desired response in a field

r_i = the response of the i th device in the field

k_i = the coefficient for the i th device

Let the Name Stand for the Response:

R = Delivered Dose, rem

T = Response of the TLD

S = Response of AN/PDR-70

G = Response of Guts

B = Response of Bare

$$S = k_0 T + k_1 G + k_2 B, \text{ so:} \quad \text{Eq. 1}$$

$$T/S = A_0 + A_1(G/S) + A_2(B/S) \quad \text{Eq. 2}$$

$$R = k_3 S + k_4 G + k_5 B, \text{ so:} \quad \text{Eq. 3}$$

$$R/S = A_3 + A_4(G/S) + A_5(B/S) \quad \text{Eq 4}$$

Equation 2 attempts to make the TLD energy response equal to the remmeter response. Equation 4 attempts to correct the remmeter response. So, dividing Eq. 2 by Eq. 4, the TLD response/rem is:

$$T/R = [A_0 + A_1(G/S) + A_2(B/S)]/[A_3 + A_4(G/S) + A_5(B/S)] \quad \text{Eq 5}$$

The NECF is the inverse of the TLD/rem. Why not divide Eq. 4 by Eq. 2 and obtain the NECF directly? Giving fitting routines too many parameters can lead to wrong results; so, the AN/PDR-70 correction factors; A_3 , A_4 , and A_5 are found first. Fitting routines work best with the unknowns in the numerator and so the known factors are put in the denominator and the unknown factors in the numerator by dividing Eq. 2 by Eq. 4.

Finding the value of the parameters

A least squares fit produces a poor set of parameters. It takes the measured TLD/Rem to be error free, but it is not. It also has the wrong goal. It minimizes the difference between the calculated and the measured TLD/Rem. A minimum difference is not wanted. The ratio (calculated TLD/Rem)/(measured TLD/Rem) should be made equal to one, since doses will be multiplied by the correction factor. Effort should not be spent on making good results better, but in making the worst values acceptable. A proper fit will compare the largest and least value of measured to calculated and make their ratio (MAX/MIN) as nearly equal to one as possible

[Vetter, 1971]. To meet these requirements, an iterative fitting procedure was used. A graphical solution was used as a starting point, because an iterative procedure can become stuck on a local minimum, which is far from the correct answer.

Discussion

Models are tested by examining the largest and smallest values of the calculated to measured ratios of the response, TLD/Rem. Since the DT-648 data included more spectra, it was used to select the model. Seven different models of the response are produced by setting different constants equal to zero (or in the case of A_3 , 1.0). They make the maximum to minimum ratios equal to 2.25 or less. The five-parameter model reduces a 700-fold variation of response with energy to 2.21. A dosimeter corrected by this equation would have a bias plus standard deviation due to energy of only 23%. The albedo dosimeter has been made as accurate as a remmeter!

One could be pleased with any of the models, but since there is a choice, there should be some reason for making it. Gauch [1993] has shown that the first few parameters extract most of the information in the model. “A model can be more accurate than the data used to build it because it amplifies hidden patterns and discards unwanted noise.” The (G/S) model is clearly the principal effect and thus best able to model unknown fields. The (G/S, B/S) model may be better able to deal with thermal neutron fields. It does improve the response in a thermal neutron field, but only from 95% to 100%. So, following Gauch, the simplest model can be selected having one coefficient, A_2 , to be determined from the data, A_3 set to 1.0, and the rest set to 0.0. The result is

$$T/R = 0.11(G/S) \text{ Therefore: } NECF = 1/(T/R) = 9.1(S/G).$$

This simple model is a good predictor of the NECF over a response range of 1,000, as seen in Figure 6.

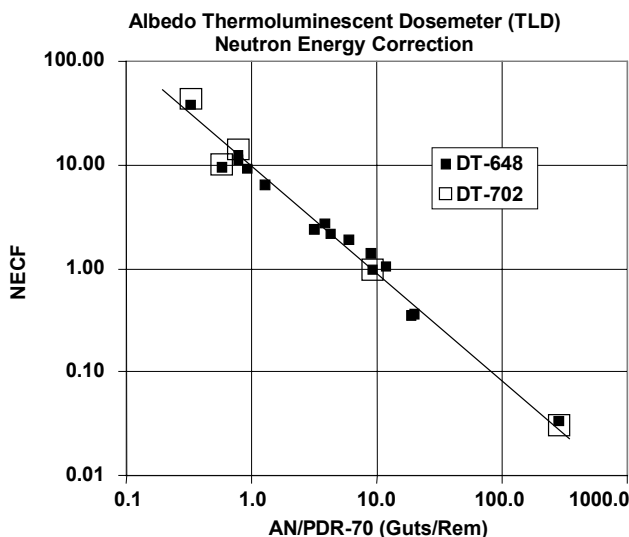


Figure 6. Simple Model of a Good NECF Predictor over a Response Range of 1,000

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Appendix A

Procedures for Determining Neutron Energy Correction Factors Using the AN-PDR/70 RADIAC

1. Background

This document was derived from Naval Dosimetry Center Technical Report 94-01, originally written for the DT-648/PD. In this appendix, given the neutron response of DT-702 similarity to DT-648, the technical report has been rewritten for the DT-702. The neutron sensitivity of DT-702, as with DT-648 dosimeters, is energy dependent and affects the response of the dosimeter when it is exposed to a neutron energy spectrum which differs from the one in which the dosimeter is calibrated.

To correct this problem, a technique was developed through a cooperative effort among the Naval Research Laboratory, the Naval Surface Warfare Center, and the Naval Dosimetry Center. This technique has been adopted in the DT-702 to correct its response for a wide range of neutron spectra. The technique generates a site-specific (based on UIC) neutron energy correction factor, which is applied to certain personnel (based on their assigned occupational code (Occ Code) on the NAVMED 6470/3). The technique is based on measurements with an AN/PDR-70 RADIAC (PDR 70), which is available throughout the Navy.

The neutron energy spectrum can vary significantly in any particular environment, depending on a variety of factors, e.g., type of neutron source, moderation or shielding of the source, structures located in the source room, construction material of the source room, distance from the source, etc. Accordingly, it is not unusual to find that the neutron spectrum (i.e., the neutron energy correction factor) varies significantly at different locations near a neutron source. Therefore, measurements at more than one location, and an estimate of the occupancy factor and dose rate at each location, are necessary in determining a site-specific neutron energy correction factor. A weight will be assigned to each NECF according to the fraction of the expected dose in that location. For example, during the operation of a therapy CLINAC personnel occupy two locations. Ninety five percent of the time they are located at the CLINAC's console with a dose rate of 0.5 mrem/hour, the remaining five percent is spent at the CLINAC's door visualizing the patient with a dose rate of 2 mrem/hour. To determine a site-specific neutron energy correction factor for these personnel, Occ Code 33, measurements would be performed at the console and door. Sample calculation (which will be done by NDC).

Location	Occupancy	Dose Rate	Rate * Occ	NECF
Console	0.95	0.5	0.475	1.2
Door	0.05	2.0	0.10	5.9
Total	1.00		0.575	2.0

$$\text{NECF} = ((1.2 * 0.475) + (5.9 * 0.1)) / 0.575 = 2.0$$

2. Equipment Requirements

- a. IM-265/PDQ - At least one is required,
- b. PDR 70 - At least one is required. More than one is useful if there is only a limited amount of time available for surveying. If more than one is used, report their individual calibration factors.
- c. Counter/Timer - At least one counter timer or pulse integrator is required for each PDR 70 in service. Acceptable pulse integrators are the WCX 1 or DIG 5 (CP1765). Be sure that the pulse integrator is set to accept negative pulses.
- d. Rulers - Carpenter's ruler, measuring tapes, levels and plumb-bobs are needed to locate detector positions.
- e. Tripods - Convenient for easy adjustment for detector height.
- f. Phillips head screwdriver - needed for PDR 70 disassembly and reassembly,
- g. Miscellaneous – data sheets (copy as needed, included on page A-6), masking tape, styrofoam blocks, and rope are all useful to position and secure detectors. Extra batteries (D cells) for RADIACs and AA cells for counter-timer may be needed.

3. Survey Guidelines

- a. The radiation source(s) should be in the configurations responsible for the largest portion of personnel exposure.
- b. The survey point(s) should reflect the area(s) where the estimated product of occupancy time and dose equivalent rate is the greatest. The product of the occupancy time and dose equivalent rate as measured on the PDR 70 should predict exposures of 10 or more millirem per issue period (usually six or seven weeks).
- c. Plan the survey in advance using floor plans of the facility to select positions of interest.
- d. The height of the measurement should coincide with the height at which the personnel dosimeter is worn at that location, e.g., 24 inches for a person sitting and 40 inches for a person standing. Measurements are made from the deck to the center of the detector.
- e. Select a suitable area to determine a background measurement.

4. Description of Measurements

At each survey point record four measurements and occupancy on one data sheet;

- a. PDR 70 with probe fully assembled,
- b. PDR 70 with probe partially assembled,
- c. PDR 70 with bare tube assembly, and
- d. IM-265/PDQ gamma measurement.

Figure A-1 is an exploded view of PDR 70 probe. The response of the detector inside the fully assembled PDR 70, (Figure A-2), is proportional to the neutron dose equivalent rate independent of neutron energy. Figure A-3 is a diagram of the partially assembled PDR 70. The neutron energy response of the detector in this configuration is proportional to the neutron energy response of the properly worn DT-702. So, the ratio of the detector response in the partially assembled PDR 70 to the fully assembled PDR 70 is a measure of the relative response of the DT-702 to the neutrons in the environment being surveyed.



Figure A-1. PDR 70 Exploded view



Figure A-2. Fully assembled PDR 70.



Figure A-3. Partially assembled PDR 70, "Guts"

Figure A-4 shows the bare tube assembly of the PDR 70 which provides additional spectral information useful in verifying the validity of the first two measurements. It also provides information on how the DT-702 dosimeter would respond if it is not attached to a moderating media.



Figure A-4. Bare Tube Assembly of the PDR 70

The IM-265/PDQ measurements provide information about the gamma radiation component of the total radiation field.

A total of 400 counts or more is required, (1000 counts is desired) for the fully assembled PDR 70 configuration. This may take several minutes, for example about 30 minutes at 0.1 mrem/hour. Other configurations may require a longer or shorter time to produce the same number of counts as the fully assembled AN/PDR-70. If the other configuration counts more slowly, the time not be longer than the fully assembled count.

For Example:

PDR 70 Configuration	Counts	Minutes
Fully Assembled	400	33
Guts	1,000	20
Bare	100	33

All PDR 70 readings must be taken with the radiacmeter attached to the detector and the scale set at $\times 10^3$. The height and orientation of the detector should be identical for each set of measurements at any given survey point. The preferred orientation is to make measurements with the long axis of the PDR 70 probe perpendicular to the direction to the neutron source. Personnel standing near the detector can significantly alter the counting rates, particularly in the partially assembled and bare tube configurations. The use of stands and support jigs can ensure the RADIAC's constant geometry. Support stands and jigs should be made of non hydrogenous / non ferrous materials (e.g., one may use a block of Styrofoam or a few steel screws). Enclosed data sheets can be reproduced locally to document data collection.

5. Calibration

If using one PDR 70 report its calibration date as one does on routine surveys. If more than one PDR 70 are used, each PDR 70, radiacmeter, and counter/timer group should be kept together. Each RADIAC group should be calibrated and the efficiency (counts per second per mrem/h) should be reported on one of the data sheets. The AN/UDM-10 will not produce a meter reading on the $\times 10^3$ scale, but will produce a response on the pulse integrator. In the partially assembled configuration, ensure the BF3 tube is pushed to the end of the inner moderator.

6. Summary

Record the calibration on one data sheet and the following survey measurements on one data sheet for each point:

- a. Fully assembled PDR 70 (Figure 2),
- b. Partially assembled PDR 70 (Figure 3),
- c. Bare tube assembly PDR 70 (Figure 4),
- d. IM-265/PDQ gamma measurement.
- e. Occupancy
 1. Percent, total should equal 100.
 2. Hours per work week, total should equal all hours in a week that the dosimeter is worn.

7. Reference

1. Naval Dosimetry Center Technical Report 94-01, Procedures for determining Neutron energy correction factors using an AN/PDR-7

NEUTRON ENERGY CORRECTION FACTOR DATA SHEET

Command: _____ UIC: _____

RADIAC Operator/Recorder: _____ Date: _____

Survey Point Location/Compartment: _____

Coordinate	Description	Measurement
X		
Y		
Z		

Occupancy Factor: _____

AN/PDR-70 Measurements

Probe Serial Number (#)	Meter Serial #	Pulse Integrator Serial #	Range Setting	Probe Configuration	Counts	Minutes	Counts min ⁻¹
			x10 ³ (1000)	Fully Assembled			
			x10 ³ (1000)	Partially Assembled			
			x10 ³ (1000)	Bare Tube Assembly			

IM-256/PDQ Measurement

Serial #	Range Setting	mR h ⁻¹

